NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Technical Memorandum No. 15.

ON THE DEFINITION OF THE STANDARD ATMOSPHERE.

By

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Translated from the French,
by
Paris Office, N.A.C.A.

April, 1921.

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On April 15, 1920, the Under Secretary of State for Aeronautics and Aerial Transport decided to adopt as Standard Atmosphere for official airplane tests in France, the atmosphere defined by the following law, known as the Law of the S.T.Aé. (Technical Section of Aeronautics):

From 0 to 11,000 m. $\theta = 15 - 0.0065\ Z$

Above 11,000 m. $\theta = \ - 56.5^{\circ}$

being the temperature in centigrade degrees at altitude Z expressed in meters. For altitude 0 the pressure is 760 mm. of mercury.

In the magazine "L'Aeronautique" Mr. A. Toussaint has already written at length on the first studies which led to the elaboration of this law.*

Since that time the results obtained have been confirmed by fuller and more abundant data which have justified the official adoption of the Law of the S.T.Aé.

The object of the present article is to give a summary exposition and discussion of the ideas and documents which form the basis of the question.

1. - UTILITY OF THE STANDARD ATMOSPHERE.

We must first say why and how we have been led to define a typical or standard atmosphere.

The performances (horizontal speed, rate of climb) of an airplane vary with the physical state of the atmosphere at the point occupied by the airplane. In point of fact, the lift and head resistance of an airplane are proportional to the density of the air. The power of the engine also varies with the pressure and density of the surrounding atmosphere, unless the engine is fitted with a special device. At about 5,500 meters the motive power is only half of what it was on the ground level.

* Study of the Performances of an airplane fitted with a supercharged engine. A. Toussaint. "L'Aeronautique" No.5, Oct., 1919, and "Review of Aéronautical Works," Nos. 2-3, p.1.

As meteorological conditions vary a good deal from day to day (the temperature at a given altitude may vary by about 25° according to the season) it follows that according to the moment when a test is made, results obtained in various experiments present divergencies which we cannot ignore; this is shown in the following example.

Let there be a Breguet XIV A2 flying at a height of 3,000 meters. At this altitude the pressure may oscillate between 520 and 535 millimeters of mercury and the density between 0.89 and 0.92. This involves a corresponding variation in the performances of the machine: 183 to 186 kilometers an hour for horizontal speed and 2.75 to 3.10 m. per second for climbing speed. These differences are important enough at the comparatively low altitude of 3,000 m., and they increase in absolute value with altitude.

So that we may be able to compare all results with each other, we define a typical or standard atmosphere, and the results of each test are brought to what they would have been if the airplane had flown in the chosen comparative atmosphere. We thus obtain homogeneous data for the various flights made by an airplane, and we are warranted in comparing different airplanes with each other. The official values of airplane performances given by the A.T.Aé. are obtained by this method.

In principle, this standard atmosphere may be chosen in an absolutely arbitrary way. In fact, it is necessary to choose an atmosphere such that, at each altitude, the values of the different characteristics of the atmosphere are pretty near the mean values.

The standard performances thus calculated will correspond to the observed average of the actual performances of the airplane. In the example mentioned above, computation gives a horizontal speed of 185 km. and a climbing speed of 2.90 m.s. Furthermore, the computation of the passage from one atmosphere to another entails a certain approximation. It is therefore necessary to reduce to a minimum the mean magnitude of the corrections to be made; this result will be obtained by choosing the standard atmosphere as just indicated.

2. - GENERAL CONDITIONS FOR DEFINING THE STANDARD ATMOSPHERE.

HYPOTHESES.- In all that follows we assume that the air is a perfect gas, and, in the absence of sufficient knowledge on this point, we assume that it is a dry gas. We shall see, moreover, that this approximation is justified by the coincidence of data calculated on these hypotheses and experimental data. Lastly, we shall ignore the variations of gravity with altitude.

At a point of the atmosphere defined by its altitude z expressed in meters above the sea level, we will consider the temperature θ_z expressed in centigrade degrees, the pressure H_z expressed in kgs. per square meter* and the specific weight a_z expressed in kgs. per cubic meter of the air at that point.

The standard atmosphere will be completely defined when, knowing the value of one of these 4 parameters, the other three are determined. Between these 4 quantities, we must therefore have three equations.

Now, in the hypotheses we have taken, we have already two relations:

1st. Equation of perfect gases.

$$1) \qquad \frac{a_z}{a_o} \quad \frac{H_z}{H_o} \quad \frac{1 + \alpha \ \theta_o}{1 + \alpha \ \theta_z}$$

2nd. The differential equation of variation of pressure with altitude.

$$2) \qquad d\,H_z = -a_z dz$$

To define the standard atmosphere we must thus have a third relation, and must take the initial conditions suitable for determining the constant of integration of the equation.

This third relation will be an experimental relation deduced from mean soundings and will express the relative variation of two of the quantities considered above. It must not be forgotten that the laws of variation of atmospheric elements with altitude, vary with time at a given place, and in space at a given moment. Consequently we must not be deceived by the word "law" which expresses a mean relation as near as possible to the actual relation, and not a physical law in the exact and rigorous sense usually attached to the term.

3. - NECESSITY OF A NEW DEFINITION.

The Standard Atmosphere now admitted by the French Army Aeronautical Department is defined by the Law of RADAU established in 1864. This law is expressed by Formula 3 given below, which satisfactorily translates the mean experimental results then known:

$$3) \qquad \theta_z = 15 - 0.08(760 - P_z)$$

the initial condition being $z = 0$ for $H = 760$.

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* In this study H_z stands for the pressure expressed in kgs. per sq.m., and l_z for the pressure expressed in mm. in mercury.

In England and Italy tables are used giving the characteristics at each altitude, but the results have not been put in the form of a law. This method of procedure is not convenient for forecasts and computations of performances.

On the other hand, the documents (results of soundings) now known on the decrease of temperature with altitude, clearly show that the law deduced from Radau's formula gives a sufficient approximation up to about 4,000 meters, and above that altitude the temperatures calculated are much too high.

4. - VARIATION OF TEMPERATURE WITH ALTITUDE.

These documents in chronological order, are:

1st. "On the decrease of Temperature with Altitude in the Paris District, after 5 Years' Observations," by Monsieur Teisserenc de Bort (Minutes of the Academy of Sciences, January 4, 1904).

The results obtained by Teisserenc de Bort at the Trappes observatory are given in Table I and Figs. 1 and 2, Plate B.20.

2nd. "Variation of Meteorological Elements with Altitude," by Professor Pericles Gamba, Director of the Geographical Observatory, of Pavia (published in September, 1918, by the Experimental Direction of the Italian Military Aviation).

Professor Gamba's results are given in Table 2 and Fig. 3, Plate B,20, and give the average of the soundings made at Pavia from 1906 to 1916.

3rd. "Variation of Temperature with Altitude," given in Table 269 of the Handbook of Modern Aeronautics, from data furnished by the Weather Bureau.

This table is given in Table 3, Fig. 4, Plate B.21. The temperatures given in the Handbook in absolute temperatures have been changed into ordinary centigrade temperatures.

4th. "Values of the Temperature of the Air from 10 years' Observation, 1906-1916," from the works of the Prussian Royal Observatory of Lindenberg (Vol.I). The mean values of the temperature are given in Fig. 5, Plate B.21 and Table 4.

On each of the Figs. 1, 2, 3, 4, 5, we have given, in dotted lines, the law of Variation of Temperature deduced from Radau's Law. All the curves have practically the same sweep; linear variation of temperature with altitude up to about 11,000 meters and approximate constancy of this temperature from that point upwards.

These documents form an abstract of numerous soundings; they may therefore be described as definitive and we propose to base them on definition of the Standard Atmosphere.

5. - NEW DEFINITION OF THE STANDARD ATMOSPHERE.

On Figs. 1, 2, 3, 4, 5, we have shown (in dot and dash) the straight line passing through the points $z = 0$, $\theta_o = 15^o$, and $z = 10{,}000$ m., $\theta = -50^o$. Up to 11,000 meters this straight line represents with sufficient accuracy the mean variation of the temperature which, from that point, becomes constant.

The Standard Atmosphere will thus be defined as follows:

1st. - Initial Conditions. For $z = 0$, $\theta_o = 15^o$, $H_o =$ 10,330 kgs. per square meter corresponding to $\rho = 760$ mm. of mercury, $a_o = 1{,}225$ kg/sq.m.

2nd. - Law of Variation of Temperature with Altitude from 0 to 11,000.

4) $$\theta_z = 15^o - 0.0065_z$$

Above 11,000

5) $$\theta_z = -56.5^o$$

We might have placed the point of discontinuity a little differently, say at 10,500 meters with $\theta = -53^o$ or at 10,750 m. with $\theta = -55^o$.

The temperature of 56.5 at 11,000 m. has been chosen by preference as being the nearest to the mean curve of Professor Gamba, whose documents seem to be the most complete.

With the help of equations (1) and (2) we can find the relations which, in the atmosphere thus defined, express the laws of variation of pressure and specific weight with altitude.

The Standard Atmosphere proposed is thus definitely characterized by the following equations:

1st. - From 0 to 11,000 meters:

Law of temperatures:

$$\theta_z = 15 - 0.0065_z$$

Law of Pressures:

$$\frac{P_z}{P_o} = \left(\frac{288 - 0.0065z}{288}\right)^{5.255}$$

Law of Specific Weights:

$$\frac{a_z}{a_o} = \left(\frac{288 - 0.0065_z}{288}\right)^{4.255}$$

2nd. - Above 11,000 meters:

Law of Temperatures:

$$\theta_z = -56.5^{\circ}$$

Law of Pressures:

$$\text{Log}\,\frac{P_{11}}{P_z} = \frac{z - 11,000}{14,600}$$

Law of Specific Weights:

$$\frac{a_z}{a_{11}} = \frac{P_z}{P_{11}}$$

In Figs. 6 and 7, Plate B.21 we have laid off the values of $\frac{a_z}{a_o}$, a_z, $\frac{P_z}{P_o}$, and P_z in function of the altitude up to 14,000 m.

6. - REMARKS ON THE PRECISION OF THE LAW.

It does not appear useful to seek the equation of the mean temperature curve, an equation of no interest, since it does not correspond to any physical phenomenon. We have endeavored to find a law which would, above all, be simple and yet be as near as possible to the mean values so that, in most cases, the corrections to be made in passing from the true to the standard atmosphere can be reduced to a minimum.

In order to verify whether the accuracy thus obtained is sufficient and also whether the hypotheses taken as a basis of calculation are sufficiently near to reality, we have compared the calculated results with the experimental results obtained by Professor Gamba for the variation of pressure with altitude. This comparison is summarized in Table 7. We thus see that the deviation is maximum between the figures found at the altitude of 11,000 meters. At that altitude it is 1.4 mm.; a variation of pressure of 1.4 mm. corresponds to a variation of altitude of 52 meters. The maximum error is thus 4.7 per 1000.

This result is a sufficient justification both of the law and of the hypotheses.

The chief inconvenience of the proposed law is that it necessitates two groups of relations, one for altitudes below 11,000 meters, the other for altitudes above 11,000 m.

This discontinuity has simply the result in certain cases of splitting the study of a problem into two parts, and certainly involves fewer difficulties than the use of a complicated formula. It seems, moreover, to be the translation of a physical phenomenon passing from the traposphere to the stratosphere, for it appears not only in the regime of temperature, but also in the regime of the winds.

7. - COMPARISON OF THE PROPOSED LAW WITH RADAU'S LAW.

This comparison is interesting because most of the holosteric altimeters and similar apparatus are graduated by Radau's Table of Pressures and we may ask whether the adoption of a new law would not cause serious confusion in these graduations. The following study will show that, with the exception of aviation altimeters, the apparatus in question are only graduated up to 3,000 meters, and that, therefore, the graduation will not be affected.

In Table 8 we have given for each thousandth meter of altitude as defined by the Law of the S.T.Aé:-

1st. The altitude at which the pressure is the same by Radau's Tables. This column thus gives the difference of graduation between S.T.Aé. and Radau Atmosphere.

2nd. The altitude at which the density is the same by the Law of Radau.

We see that, for pressure, the corrections are negligible up to and including 4,000 meters and that, consequently, the adoption of the proposed law will not interfere with the graduation of the apparatus in current use.

R E S U M E

The S.T.Aé. Law now officially adopted in France is thus simple, convenient, and sufficiently accurate. The official performances of airplanes effected in France can thus all be compared with each other. But unfortunately each country has still its own definition of a Standard Atmosphere. An agreement on this point does not seem to be impossible. In point of fact, the documents quoted above show that in Western Europe the climatic conditions are sufficiently similar to render possible the application of one and the same law to the whole region. Such an agreement would enable each country to profit by the official data of other countries, and great facilities would accrue for the issue of flying certificates, the calculation of flight bonuses, and, in general, for international commercial aviation.

NOTE. - We would point out that similar work has been done by Mr. Soreau*; he took as a basis 40 soundings only, and his conclusions have been adopted by the International Aeronautical Federation.

Seeking the equation of the mean curve of variation of pressure with altitude deduced from these experiments, Mr. Soreau arrived at the following formula:

$$z = 5(3064 + 1.73P - 0.0011P^2) \text{ Log } \frac{760}{P}$$

where z is the altitude in meters and P the pressure in millimeters of mercury,

As we have remarked above, considering the character of the law sought, there is no theoretical reason for endeavoring to translate rigorously the mean curve of a certain number of experiments, all the less so as this number is extremely limited. The complication resulting from the above formula thus serves no good purpose. Moreover, it is not so accurate as the S.T.Ae. Law

* Minutes of the Academy of Sciences, December 1, 1919.
"Aerophile" November 1-15, 1919.

for all the soundings studied by Mr. Soreau were made in Winter and Spring, and Professor Gamba's work has shown that the mean pressure during those seasons is lower than the mean annual pressure. For an altitude of 5,000 meters, the difference between the two means is 4 millimeters of mercury, which, at that altitude corresponds to a difference of 75 meters, that is, an error of 15 per 1000 on the altitude.

TABLE I.

VARIATION OF TEMPERATURE

With Altitude in the Paris District, according to Five Years' Observations.

By

Teisserenc de Bort.

Minutes of the Academy of Sciences, January 4, 1904.

Series A: 581 Balloons. Series B: 141 Ascensions which reached an Altitude of 14 Kilometers.

	Winter		Spring		Summer		Autumn		Amplitude	
	A	B	A	B	A	B	A	B	A	B
Ground level	+1.7	+1.9	+5.1	+5.1	+13.5	+13	+8.0	+7.5	13.7	13.4
500	+1.1	+1.4	+5.1	+4.7	+13.9	+13.6	+8.3	+7.7	14.4	15
1,000	-0.4	-0.2	+3.4	+2.4	+11.8	+11.8	+6.4	+6.1	14.7	14.6
1,500	-1.7	-0.4	-0.1	+0.1	+9.2	+9.7	+3.4	+4.0	13.3	14.6
2,000	-3.7	-1.4	-2.6	-2.1	+6.8	+7.3	+2.3	+2.2	13.5	14.3
2,500	-5.7	-3.7	-3.9	-4.3	+3.3	+5	+0.1	+0.4	13	13.8
3,000	-8.2	-6.0	-7.4	-6.4	+1.7	+2.1	-2.2	-1.7	13	12.5
3,500	-10.9	-8.7	-10.0	-9.3	-0.4	+0.2	-4.7	-4.2	13.7	13.9
4,000	-13.6	-10.9	-13	-12.2	-3.4	-2.7	-7.5	-6.5	13.6	12.6
4,500	-16.7	-14.2	-16	-15.2	-5.9	-5.3	-10.2	-9.3	13.8	13
5,000	-19.8	-17	-19.3	-18.5	-9.3	-8.3	-13.4	-12.4	13.7	13.3
6,000	-26.4	-23.7	-26	-25.2	-15.3	-14.8	-19.8	-18.7	14.4	12.5
7,000	-33.6	-31.5	-33.6	-32	-22.3	-21.7	-26.8	-26.8	14.1	12.6
8,000	-40.8	-39	-40.1	-39	-29.9	-29.3	-34.1	-33.5	13.7	12.5
9,000	-47.4	-46.9	-47.1	-46.7	-37.9	-38	-41.8	-41.4	12.3	11.8
10,000	-52.9	-54	-50.9	-52.7	-45.2	-45.3	-48.3	-48.3	10.1	
11,000		-57.9		-53.6		-50.3		-54.4		9.2
12,000		-57.9		-53.1		-52.7		-57.1		9.1
13,000		-56.9		-52.2		-51.5		-57.1		9.9
14,000		-55.5		-52.5		-51.3		-57.1		9.9

TABLE 2.

VARIATION OF TEMPERATURE

with Altitude

According to Professor Gamba.

Altitude	Pressure	Temperature	Density
0	761	11.2°	1.24340
500	716	9.3°	1.17773
1,000	675	7.5°	1.11748
1,500	634	5.1°	1.05861
2,000	596	2.3°	1.00536
2,500	560	- 0.6°	0.95052
3,000	526	- 3.5°	0.90639
3,500	494	- 6.4°	0.86053
4,000	463	- 9.6°	0.81634
4,500	433	-12.9°	0.77349
5,000	406	-16.3°	0.73459
5,500	379	-19.7°	0.69500
6,000	354	-23.5°	0.65900
6,500	330	-27.1°	0.62337
7,000	309	-31.7°	0.59480
7,500	288	-34.6°	0.56119
8,000	268	-38.4°	0.53065
8,500	249	-41.8°	0.50031
9,000	231	-45.2°	0.47112
9,500	214	-47.9°	0.44166
10,000	199	-50.9°	0.41627
11,000	171	-55.1°	0.36461
12,000	146	-56.3°	0.31302
13,000	124	-56.3°	0.26585
14,000	106	-54.7°	0.22561
15,000	90	-55.6°	0.19235

TABLE 3.

VARIATION OF TEMPERATURE WITH ALTITUDE

According to the Data of the Weather Bureau.

Altitude	Temperature			
	January	April	July	October
0	+ 3	+ 9	+16	+10
1,000	- 2	+ 3	+10	+ 6
2,000	- 6	- 3	+ 5	+ 2
3,000	-10	- 8	0	- 3
4,000	-16	-14	- 6	- 9
5,000	-23	-21	-12	-15
6,000	-30	-27	-18	-22
7,000	-36	-34	-26	-28
8,000	-43	-41	-32	-35
9,000	-49	-47	-39	-42
10,000	-53	-51	-47	-49
11,000	-56	-54	-51	-53
12,000	-56	-53	-51	-54
13,000	-57	-52	-50	-55
14,000	-57	-52	-51	-56

TABLE 4.

STANDARD VALUE

of the

TEMPERATURE, PRESSURE, AND SPECIFIC WEIGHT

of the Air

According to 10 years' Observations (1906-1916),

Taken by Sounding-Balloons at Lindenberg Observatory.

Altitude	Near Ground 116 m	1,000	2,000	3,000	4,000	5,000	6,000	7,000
Annual Mean	8.37°	4.31°	-0.69°	-5.69°	-11°67	-18°13	-25°12	-32.52°

Altitude	8,000	9,000	10,000	11,000	12,000	13,000	14,000
Annual Mean	-39°77	-46°32	-51°46	-53°96	-54°13	-53°41	-53°01

TABLE 5.

S.T.Aě. STANDARD ATMOSPHERE

(Proposed from 0 to 11,000 meters)

Law of Temperatures = $\theta = 15 - 0.0065\ Z$

Law of Pressures $\mu = \frac{P_Z}{P_o} = \left(\frac{288 - 0.0065\ Z}{288}\right)^{5.256}$

Law of Densities $\delta = \frac{A_Z}{A_o} = \left(\frac{288 - 0.0065\ Z}{288}\right)^{4.256}$

Z	$\mu = \frac{P_Z}{P_o}$	P_Z	θ	A_Z	$\delta = \frac{A_Z}{A_o}$
0	1.000	760	+15	1.225	1.000
500	0.942	715.9	+11.75	1.166	0.9526
1,000	0.887	674.1	+ 8.5	1.111	0.9074
1,500	0.8342	633	+ 5.25	1.058	0.8637
2,000	0.784	596.1	+ 2	1.006	0.8215
2,500	0.7369	560	- 1.25	0.9567	0.781
3,000	0.6916	525.7	- 4.25	0.9089	0.742
3,500	0.6488	493.1	- 7.75	0.863	0.704
4,000	0.6081	462.2	-11	0.8189	0.6685
4,500	0.5695	432.8	-14.25	0.7766	0.6339
5,000	0.532	405	-17.5	0.7359	0.6002
5,500	0.4982	378.6	-20.75	0.6953	0.5675
6,000	0.4654	353.7	-24	0.6595	0.5383
6,500	0.4344	330.2	-27.25	0.6236	0.5090
7,000	0.4022	307.8	-30.5	0.5889	0.481
7,500	0.3773	286.7	-33.75	0.5563	0.4541
8,000	0.3511	266.8	-37	0.5249	0.4285
8,500	0.3264	248.1	-40.25	0.4948	0.4039
9,000	0.3031	230.4	-43.5	0.466	0.3804
9,500	0.2812	213.7	-46.75	0.4386	0.358
10,000	0.2606	198.1	-50	0.4124	0.3366
10,500	0.2413	183.4	-53.25	0.3874	0.3163
11,000	0.223	169.6	-56.5	0.3636	0.2968

TABLE 6.

S.T.Aé. STANDARD ATMOSPHERE

(Proposed above 11,000 meters)

(Law of Temperatures: $\theta_Z = \theta_{11,000} = -56.5$ (Isotherm)

(Law of Pressures: $\log \frac{P_{11}}{P_Z} = \frac{Z - 11,000}{14,600}$

(Law of Densities: $\frac{A_Z}{A_{11}} \; \frac{P_Z}{P_{11}}$

Z	$\frac{P_Z}{P_{11}}$	P_Z	θ	A_Z	$\frac{A_Z}{A_{11}}$	$\gamma = \frac{P_Z}{P_o}$	$\delta = \frac{a_Z}{a_o}$
11,000	1.000	169.6	-56.5	0.3636	1.000	0.2231	0.2968
11,500	0.9241	156.7	"	0.336	0.9241	0.2062	0.2743
12,000	0.8541	144.8	"	0.3106	0.8541	0.1906	0.2535
12,500	0.7893	133.8	"	0.287	0.7893	0.1761	0.2343
13,000	0.7299	123.7	"	0.2652	0.7299	0.1628	0.2165
13,500	0.6741	114.3	"	0.2451	0.6741	0.1504	0.2001
14,000	0.623	105.6	"	0.2265	0.623	0.139	0.1849
14,500	0.5758	97.88	"	0.2098	0.5758	0.1288	0.1713
15,000	0.5321	90.25	"	0.1935	0.5321	0.1187	0.1579

TABLE 7

Altitude	S.T.Ae.	Gamba	Dif. of pres-sures	Dif. % of pres-sures	Dif. Alt. per mm. of Mercury (in meters)	Real dif. of alt.	Dif. % of altitude
0	760	761	1	0.1315	11.08	11.08	
1,000	674	675	1	0.1984	12.22	11.22	1.1
2,000	596	596	0	0	12.8	0	0
3,000	525.7	526	0.3	0.0571	15.1	4.03	0.13
4,000	462.2	463	0.8	0.173	16.6	13.28	0.33
5,000	405	406	1	0.247	18.48	18.48	0.369
6,000	353.7	354	0.3	0.085	20.67	6.201	0.103
7,000	307.8	309	1.2	0.391	23.1	27.72	0.30
8,000	266.8	268	1.2	0.451	25.96	31.155	0.39
9,000	230	231	1	0.435	29.21	29.21	0.32
10,000	198	199	1	0.505	33.3	33.3	0.33
11,000	169.6	171	1.4	0.825	37.4	52.36	0.47
12,000	144.8	146	1.2	0.83	43.8	52.56	0.438
13,000	123.7	124	0.3	0.2425	51.4	15.42	0.119
14,000	105.6	106	0.4	0.3785	60	24	0.17
15,000	90.20	90	0.25	0.277	70.5	17.625	0.118

TABLE 8

S.T.Ae. Atmosphere	Radau Atmosphere	
	Pressure	Density
1,000	1,000	990
2,000	2.000	1.975
3,000	3.000	2.950
4,000	4.000	3.900
5,000	5.050	4.875
6,000	6.100	5.825
7,000	7.150	6.675
8,000	8.250	7.425
9,000	9.350	8.375
10,000	10.450	9.350

Translated by Paris Office, N.A.C.A.

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ON THE DEFINITION OF THE STANDARD ATMOSPHERE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED
DRAWN
CHECKED
APPROVED

B 22

Variation of temperature with altitude according to the data of the WEATHER BUREAU

Legend

J: January (Winter) Jl: July (Summer)
A: April (Spring) O: October (Autumn)
——·——: Law of S.T.Ae
- - - - - - Radou's Law

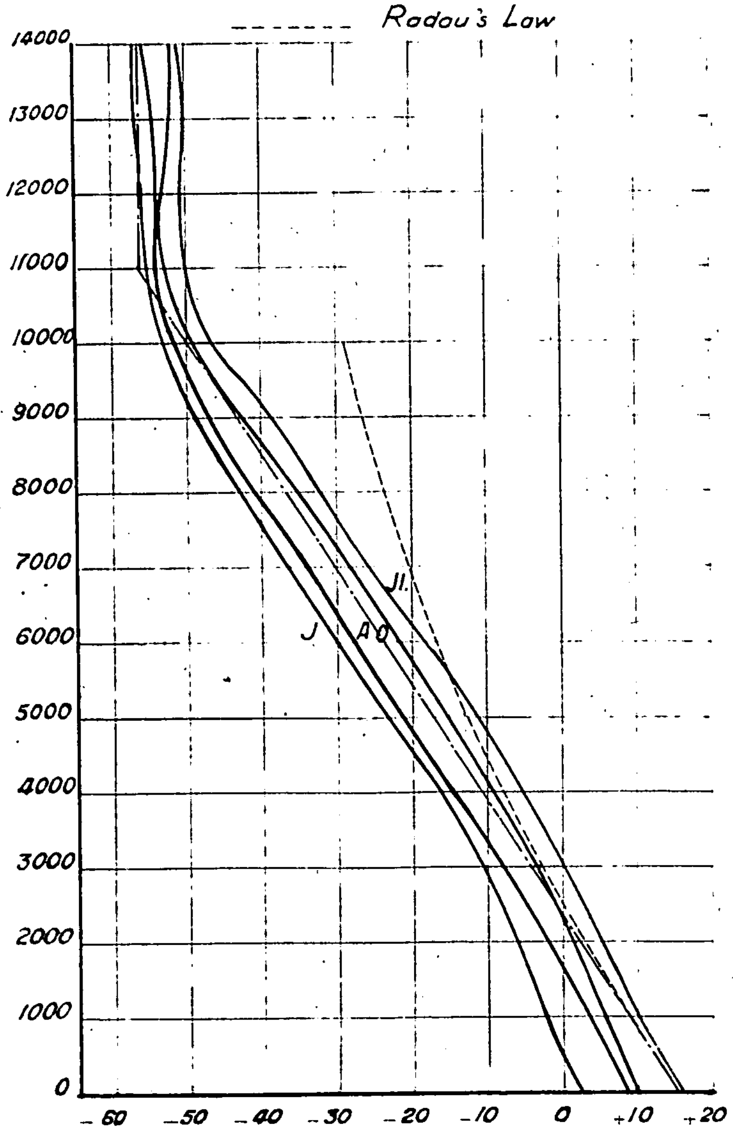

FIG. 4

Variation of temperature with altitude according to LINDENBERG OBSERVATORY

Curve of Lindemberg Observatory ————
Law of S.T.Ae ——·——·——
Radou's Law - - - - -

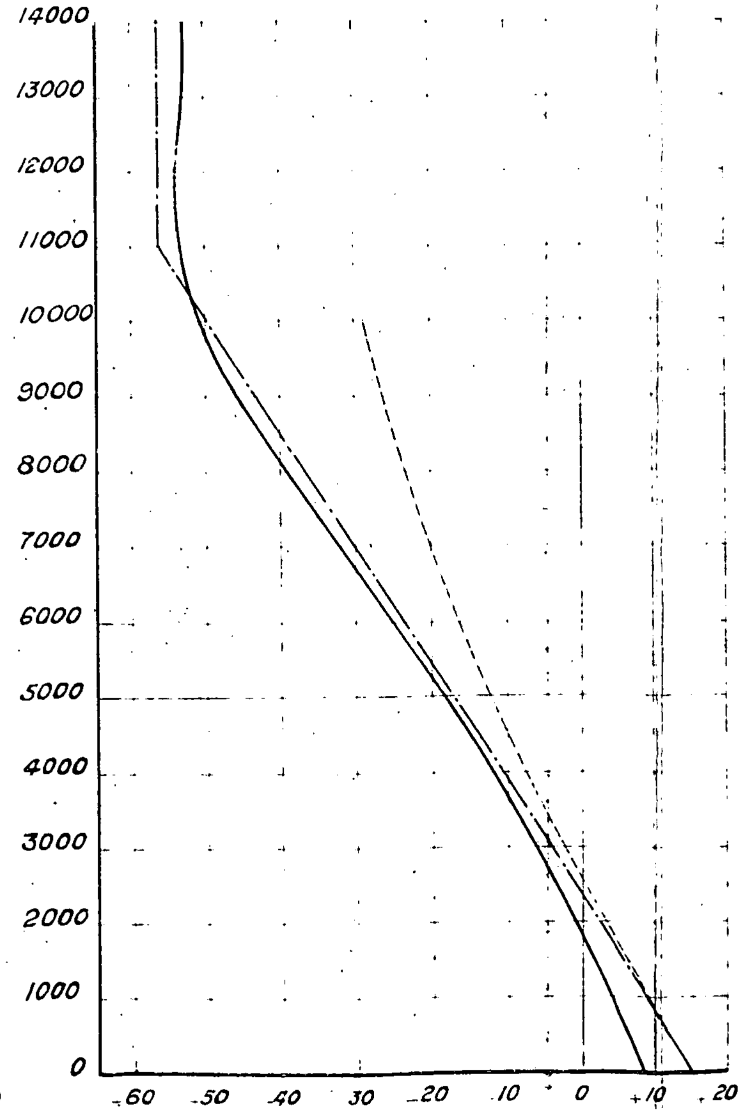

FIG. 5

Variation of density with altitude in standard atmosphere according to the law of the S.T.Ae

From 0 to 11000: Law of temperatures $\theta = 15 - 0.0065z$; Law of density $\delta = \frac{\partial_z}{\partial_0} = \left(\frac{288 - 0.0065z}{288}\right)^{4.256}$

From 11000 to 14000: Law of temperatures $\theta_z = \theta_{11000} = -56.5$ (Isotherm); Law of density $\frac{\partial_z}{\partial_{11}} = \frac{P_z}{P_{11}}$

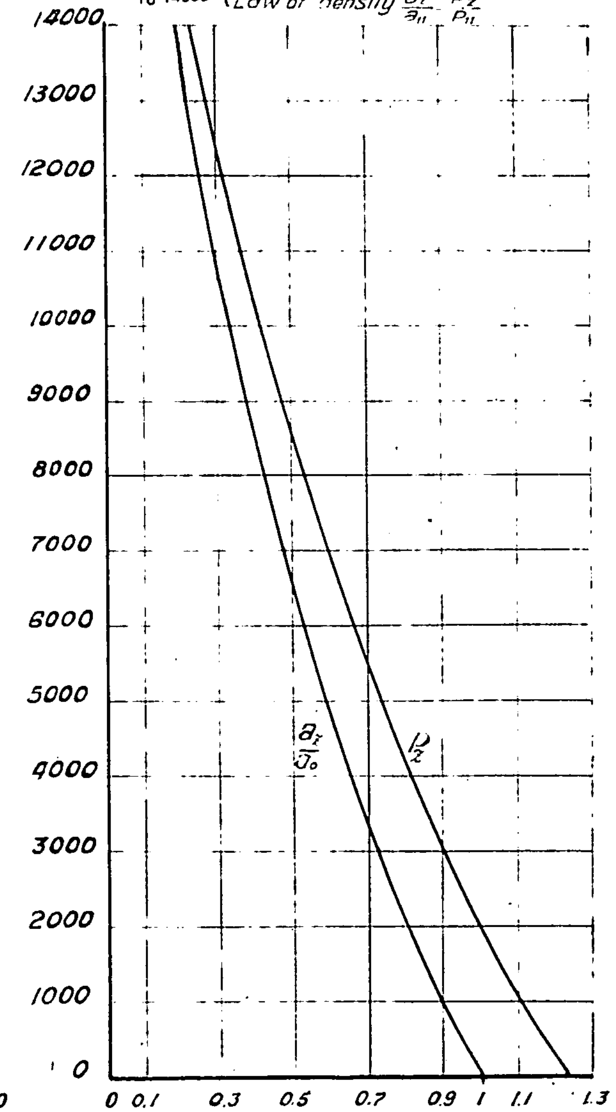

FIG. 6

Variation of pressure with altitude in standard atmosphere according to the law of the S.T.Ae

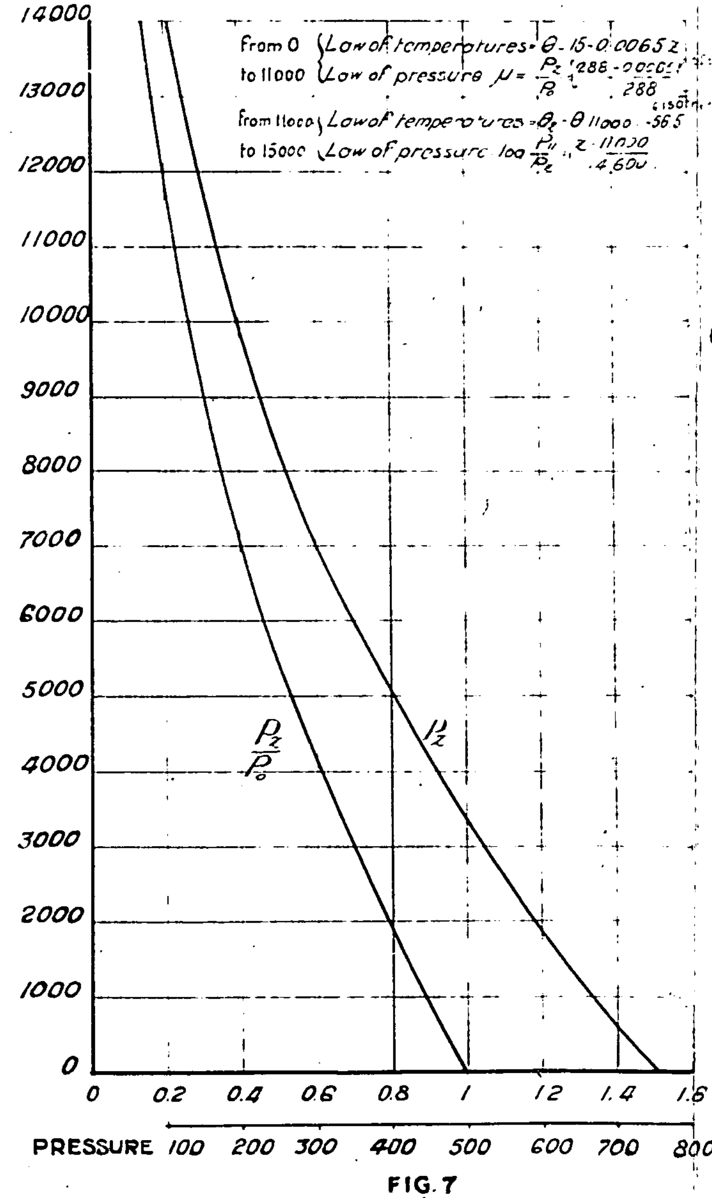

FIG. 7

P. GRIMAULT.
ON THE DEFINITION OF TH[E]
STANDARD ATMOSPHERE

NATIONAL ADVISORY COMMITTE[E]
FOR AERONAUTICS PARIS OFFIC[E]

DESIGNED
DRAWN Touta 5/12/920
CHECKED W. Margoulis
APPROVED 7/2/2.

B 21

Variation of temperature with altitude in the Paris District according to **TEISSERENC DE BORT**
Series A. 581 Balloons

W: Winter - S: Spring - Su: Summer - A: Autumn
Law of the S.T.Ae
Radau's Law

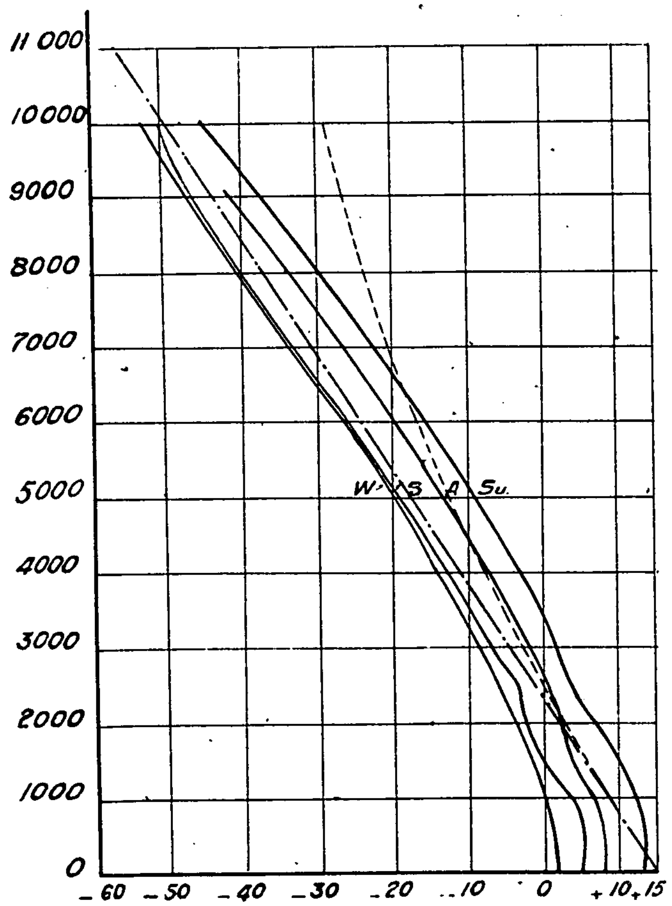

FIG. 1

Variation of temperature with altitude in the Paris District according to **TEISSERENC DE BORT**
Series B. 141 Ascensions which reached an altitude of 14 kilometers

W: Winter - S: Spring - Su: Summer - A: Autum
Law of S.T.Ae
Radau's Law

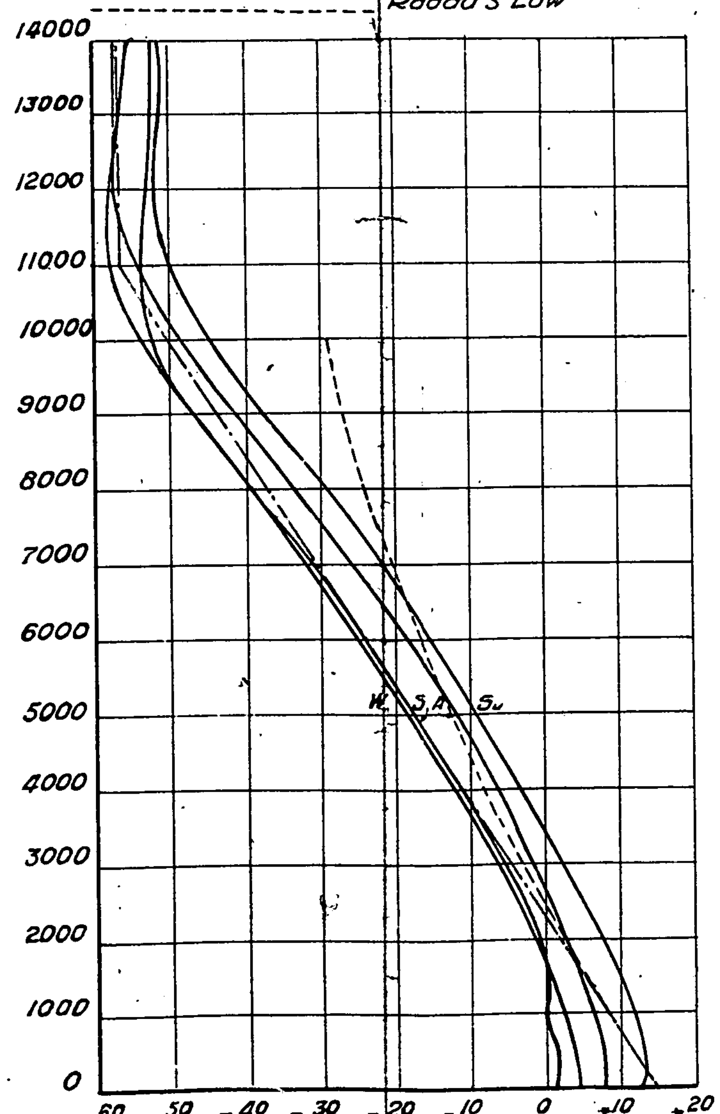

FIG. 2

Variation of temperature with altitude according to ~~the~~ Professor **GAMBA**

Gamba's Curve
Law of S.T.Ae
Radau's Law

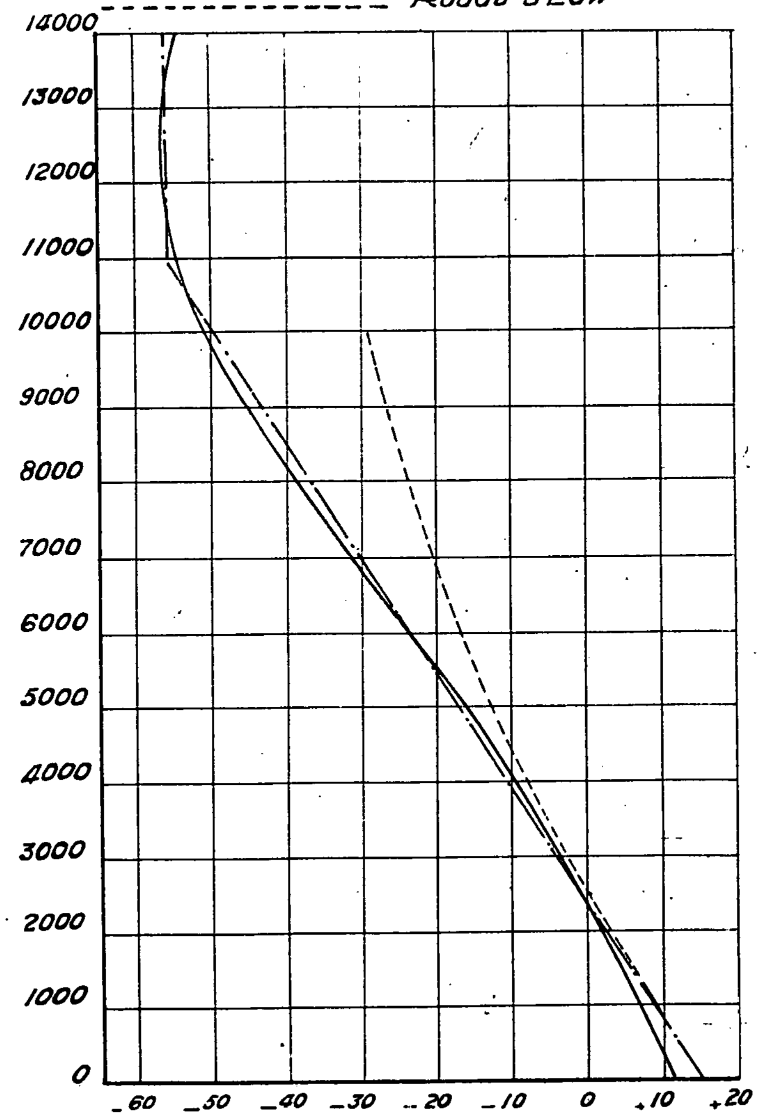

FIG. 3